DESIGN OF CRASH TRACK TROLLEY

Bachelor Thesis – Mechanical Engineering
Product Development

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HÖGSKOLAN I BORÅS
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Abstract
This thesis was performed in the summer of 2017 at Autoliv Test Center in Vårgårda. Autoliv is the world’s leading automotive safety supplier and developer of safety equipment for the vehicle industry. Autoliv also performs crash testing for customers wanting their concept cars tested before production.

In crash testing, the vehicle is accelerated by a crash track trolley that connects the vehicle to a steel wire driven with a hydraulic propulsion system. The trolley is a steel construction positioned inside the crash track gripping the wire with a clamping mechanism. The crash testing industry is in constant development due to new safety systems, harder regulations and tougher requirements from governments and vehicle safety organizations. A recently introduced crash test called the NHTSA Oblique 90km/h had issues being performed due to slip between the clamping system and steel wire.

The goal of this thesis has been to develop a new crash track trolley that does not malfunction during crash testing. The work has been aimed at designing a trolley that functions at current conditions without implications on the crash track or propulsion system. Four concepts have been designed in 3D, evaluated in a concept matrix, discussed with senior staff and one concept was chosen for further development. The effects of the new design on components have been investigated and adjustments were made. A FEM-analysis was done on the winning concept to look into the physical integrity of the new trolley as well as the potentials in weight optimization.

The result was a new trolley plate, elongated by 20 cm and thinned by 10 mm. The same plate weight was preserved and the trolley design was recommended by senior staff at ATC. The trolley was discussed and further recommendations were given.

Keywords: crash testing, crash track trolley, product development
Sammanfattning
Det här examensarbetet genomfördes sommaren 2017 på Autoliv Test Center i Vårgårda. Autoliv är världens ledande leverantör av säkerhetsutrustning och utvecklare av säkerhetssystem för fordonsindustrin. Autoliv genomför även krockprovning för kunder som vill genomföra tester av deras bilar före produktion.

Vid krockprovning accelereras testfordonet av en krockprovningstrolley som kopplar samman fordonet med en vajer vilket drives genom ett hydrauliskt framdrivningssystem. Trolley är en stålkonstruktion som är placerad i krockspåret vilket griper fast i stålvajern med ett klämsystem. Krockprovningsindustrin är i ständig utveckling med nya säkerhetssystem, hårdare regler och tuffare krav från myndigheter och fordons säkerhetsorganisationer. Ett nyligen introducerat test kallat NHTSA Oblique 90km/h hade svårt att genomföras på grund av att klämmekanismen slirat vid genomförandet.

Målet med examensarbetet har varit att ta fram en ny krockprovningstrolley som fungerar när den genomför NHTSA Oblique 90km/h. Arbetet har varit inriktat på att designa en trolley som fungerar under nuvarande förhållanden utan att göra inverkningar på krockbanan eller framdrivningssystemet. Fyra koncept har designats i 3D, utvärderas i en konceptmatris, diskuterats med erfaren personal och ett koncept valdes ut för fortsatt utveckling. Effekterna av den nya designen på komponenter har undersökts och justeringar genomfördes. En FEM-analys gjordes på det vinnande konceptet för att bedöma hållfastheten på trolleyn samt potentialen för Viktoptimering.

Resultat var en ny trolleyplatta, 20 cm längre och 10mm tunnare. Den ursprungliga plattans vikt bevarades och designen rekommenderades av personal på ATC. Trolley diskuterades och ytterligare rekommendationer gavs.

Nyckelord: krockprovning, krockprovningstrolley, produktutveckling
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Appendix 1 FEM-Analysis
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Preface

Firstly, this thesis could not have been performed without the possibility to work at the crash track, interact with the staff and use the resources available at Autoliv Test Center. I want to express my deepest gratitude to Autoliv for giving me the opportunity to finish my bachelor thesis with such an interesting subject – crash testing.

I want to thank Erik Bjelkemyr for the time you have spent and the guidance you have given me during the short period I was at ATC. I also want to thank every staff member and especially Mats Anderson, Per Andersson, Kenneth Backman, Henrik Hermansson and Peter Hast. Your input and suggestions have helped me greatly throughout the process.

Borås 2017

*Uros Duvnjak*
1. Introduction and problem description

In this chapter the background, purpose and limitations of the thesis are presented. In addition there is a description of the company and the current crash test procedure at Autoliv Test Center - where this thesis was performed.

1.1 Background

Legislation regarding vehicle safety extends far back in time. Already when the first cars were introduced in Germany in the beginning of the 20th century there were legislative proposals about liability for use of vehicles. The industry soon experienced enormous growth becoming the economic backbone in several countries around the world. The development of vehicle safety would however linger until the mid-60s when car companies realized the potentials safety had in extended competitiveness. (Seiffert, Wech 2003)

In 1979 the New Car Assessment Program (NCAP) was created by the National Highway Traffic and Safety Administration (NHTSA) in the United States with the purpose of encouraging companies to build safer cars and for customers to buy them. The first crash test was performed on May 1979, which was a full frontal crash test at 56km/h. The crash test would become the first standardized protocol used to analyze the constructional behavior of a vehicle during collision. (NHTSA 2017)

In time protocols have changed. One standardized frontal crash test has become several different crash tests including offset, side, and pedestrian collision. The protocols are still maintained by the NHTSA and NCAP who constantly are looking to reduce fatal injuries in traffic by improving their test methods. Autoliv Test Center in Vårgårda has since the 1970s performed tests on a daily basis for car companies wanting their concept vehicles evaluated before production. The facility has grown into a modern laboratory capable of many advanced testing methods and focusing specifically on vehicle safety. (Autoliv Test Center 2017)

With the introduction of new protocols, limitations at the facility have appeared causing the need for development at the crash track. One of these limitations regards the facilities crash track trolley which is in need of reconstruction. This thesis is carried out in cooperation with Autoliv Test Center with the purpose of designing a new trolley that functions at all times.
1.2 Autoliv Test Center

Autoliv is the world’s largest automotive safety supplier. Autoliv develops, tests and manufactures safety systems for the vehicle industry through two business segments; Passive Safety and Electronics. In Passive Safety, which includes airbags, seatbelts and steering wheels, Autoliv holds a market share of 39% in the global market. In Electronics, which focuses on radar, night vision and cameras Autoliv holds about 20% of the market share. Autoliv’s mission is to be the leading supplier of safety systems with the goal to save lives through innovation. (Autoliv n.d.)

![Figure 1. Outdoor car to car crash test at Autoliv in Vårgårda (Autoliv Test Center 2017)](image)

Autoliv Test Center (ATC) is part of the Autoliv Group and is a Swedish certified laboratory. ATC performs simulation, construction and testing of products within many areas and especially vehicle safety. Testing at ATC involves crash testing, component testing and calibration of instruments. Within crash testing ATC is able to perform both indoor and outdoor testing. The possibilities and limitations at the facility can be seen in table 1. (Autoliv Test Center 2017)

<table>
<thead>
<tr>
<th>Indoor testing</th>
<th>Outdoor testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>One mobile vehicle and one stationary vehicle</td>
<td>Both vehicles mobile</td>
</tr>
<tr>
<td>Frontal, rear-end and side collision</td>
<td>Frontal, rear-end and side collision in several angles</td>
</tr>
<tr>
<td>Static rollover test</td>
<td>Static rollover test</td>
</tr>
<tr>
<td>Velocity up to 80 km/h</td>
<td>Velocity up to 100 km/h</td>
</tr>
<tr>
<td>Vehicle weight up to 8000 kg</td>
<td>Different velocity on vehicles</td>
</tr>
<tr>
<td>-</td>
<td>All vehicle types</td>
</tr>
</tbody>
</table>
1.3 Indoor crash test procedure

The current test procedure is schematically illustrated in Figure 2. The setup consists of a driving hydraulic engine, test track with passing steel wire, several flywheels, trolley and a mobile control system positioned on the test vehicle. The test vehicle is connected to the trolley which is pulled along the test track at desired speed. The trolley is fixed to the wire with a clamp mechanism. Crash test data is registered with the control system. The engine has no braking system which requires an external braking method at the end of the crash track. The braking system consists of brake tubes that slow the trolley by deforming.

Figure 2. Schematic illustration of a crash test
1.4 NHTSA Oblique 90km/h issue

NHTSA Oblique 90 km/h is a test recently introduced by the NHTSA due to studies showing that fatal accidents still occur during frontal collision even with the existence of modern safety systems and crashworthy vehicle structures. Reports have shown that the main cause has been exceedingly severe crashes or limited horizontal structural engagement which means corner impacts, oblique crashes and oblique corner impacts. (Bean et al. 2009)

The NHTSA Oblique differs from current frontal impact testing methods due to the vehicle being stationary and a mobile barrier being accelerated. The advantage of performing this method is primarily the possibility to compare test results. Since the same barrier is accelerated, the impact and energy exercised on the test vehicle is identical each time. (Saunders, Parent & Ames 2010)

![NHTSA Oblique 90 km/h test setup](saunders家长ames2010)

The test is performed by accelerating a mobile barrier weighing 2500 kg to 90 km/h, crashing it into a vehicle positioned at 35% oblique angle. The setup can be seen in figure 3. This is considered by the staff at ATC to be one of the most demanding tests ever performed at the facility due to the high mass and speed of the test. When it was performed for the first time the barrier was unable to obtain the required speed of 90 km/h. The cause of the issue was the trolley clamp system which was unable to grip the wire with enough pressure causing slip between the wire and clamp leading to an unstable acceleration phase. The obtained speed was 67 km/h. (Andersson¹)

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¹ Per Andersson, Expert Test Engineer, conversation 30 May 2017
The issue was solved temporarily by connecting the two trolleys that already exist on the crash track. Since both trolleys have separate clamping systems - the clamp force was increased and the test was successful. However, connecting a second trolley to the wire causes the weight to double leading to a large amount of kinetic energy being produced. This puts high strain on the facility, track and especially the brake tubes whose function is to absorb all energy. The double trolley solution can be seen in figure 4. (Bjelkemyr²)

![Figure 4. Double trolley – double clamp solution. Total weight: 160kg](image)

1.5 Purpose

The purpose of this thesis was to design a new trolley that does not slip when performing the NHTSA Oblique 90km/h. The goal has been to develop a concept that works at current conditions without implications on the crash track. The new trolley should not exceed the weight of the double trolley solution.

1.6 Limitations

The work is aimed at the trolley and directly connecting parts. No change on track, propulsion or wire system. There is no requirement to deliver a finished product, only a concept with drawings.

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² Erik Bjelkemyr, Group Manager Crash & Active Safety Testing, meeting 10 May 2017
2 Technical Framework

In this chapter parts of importance at the crash track are explained more carefully. The trolley is presented in detail as well as the clamp mechanism, braking system and maintenance procedures.

2.1 Crash track

The crash track consists of beams mounted on concrete floor. The steel wire is driven inside the track between I-beam and U-beams. Due to dangerous vibrations that occur during high-speed testing a steel plate is constructed in the outside layer to separate the track from the rest of the building. The purpose of the middle beam between the track and outer layer is to mount mechanical instruments for specific tests. Track length is 78 meters but maximum possible acceleration length is 70 meters due to barrier, trolley release and braking system.

In figure 6 a cross section of the crash track can be seen. The wire orbits between the I-beam and U-Beams around the crash track.
2.2 Crash track trolley

The trolley used at the facility is a robust steel construction able to withstand great strain during the testing process. Previously it was made in aluminum but had problems with the construction bending. It was reconstructed into steel which strengthened the trolley but increased the weight. The front view of the trolley can be seen in figure 7.

![Figure 7. Current trolley. Measure: 525x272x40 mm. Weight: Approximately 80 kg](image)

The trolley is massive in regards to modern trolleys constructed by crash track manufacturing companies. This has an advantage with the possibility to mount adapters and locking mechanisms since there is plenty of room on the construction. There is also a possibility to make adjustments to the trolley when new problems arise.

![Figure 8. Top view. The red pin locks the trolley in place when it is not being used](image)
In figure 9 a 3D model of the trolley with parts of importance can be seen. The trolley consists of the removable adapter (1) which is used to connect barriers to the trolley for certain tests. The trolley plate (2) which connects all separate parts and acts as the base of the trolley. The clamp mechanism which consists of the upper (3) and lower (4) part of the clamp. Several steel pins connect the parts together, with number 5 being of importance, explained further in this chapter. A third middle part of the clamp which was not designed is further explained in chapter 2.3. The third part is used to tighten the clamp mechanism.

Figure 9. 3D design of trolley and components

The lower part of the trolley and clamp can be seen in figure 10. Two wheels, seen on the upper left and right part of the picture, roll towards the rail to position the trolley correctly. The support attachments, positioned to the left and right of the clamp, stabilize the steel wire when clamp force is applied.

Figure 10. Bottom view of trolley
2.3 Clamp mechanism

In figure 11 a clamp removed from the track can be seen illustrating the different positions of the clamp mechanism. The clamp has four different positions which are of relevance. (1) The clamp is mounted on the trolley but the clamp is loose. (2) The clamp is tightened at the steel wire, which is only done when testing is performed. To be able to remove the trolley from the crash track, the clamp pin (3) needs to be removed; this causes the clamp to collapse (4) and enables removal from the wire. The pin needs to be removed from the clamp while the trolley still is positioned inside the track. This causes some issues for the technicians since the work is done in an awkward position.

The clamping method has been developed in Vårgårda and was specially made for the track at ATC and is a method that has functioned well in the past. Clamp maintenance is performed by removing the trolley from the track with an overhead crane and broken parts are easily replaced at the workshop which gives flexibility for the staff.³

³ Henrik Hermansson, Lab Technician, interview 2016-05-24
To perform clamp maintenance the trolley needs to be moved to a section of the track that is detachable. The section cuts are seen in figure 12. The detachable part of the track is specifically made for the current trolley and is lifted with an overhead crane after removing the attaching to the concrete.

Figure 12. Detachable section of track. Total length: 590mm
2.4 Braking method

The propulsion system at the crash track does not have a braking system. The track uses an external method for braking which is separated from the hydraulic engine. This method is performed by mounting two steel tubes at the end of the track. The tubes absorb all kinetic energy produced during the acceleration phase by deforming when the trolley collides with the tubes. For this braking system to work properly the clamp needs to release from the wire before impact, otherwise the machinery is in risk of breaking down since all kinetic energy would be absorbed entirely by the propulsion system.

![Figure 13. Elevation mechanism for release of clamp (1) and brake tubes (2) before crash test](image)

The braking method can be seen in figure 13 and 14 where an elevation fixture (1) is mounted. When the elevation is passed by the trolley, the grip is lifted and released from the wire. This allows the wire to continue its orbit along the track without the need for braking while the trolley collides with the tubes (2).

![Figure 14. Deformed brake tubes after crash test](image)
3 Method

In this chapter the different methods used to perform the thesis are presented. The chapter contains the basis for performing a feasibility study, concept development and FEM-analysis. How the different methods were applied in the thesis is also explained.

3.1 Feasibility Study

A feasibility study is an unbiased investigation with the purpose of acquiring information about design, technology and market for potential product development. During the study an analysis of different technical solutions should be made to investigate all potential conditions to minimize the need for resource demanding construction and test operations. The results of a feasibility study should lead to first requirement specifications which determine what the purpose of the product is. (Johannesson, Persson, Pettersson 2004)

Understanding the customer’s needs is a vital part for all projects directed at product development. There are several different ways to approach the customer to gain information and understanding. One example is customer interviews where the workplace is visited and the product is used. By taking part in the work of the employees, a better understanding of the technical possibilities can be achieved. (Bergman & Klefsjö 2014)

This thesis was initiated with a feasibility study to map the function and design of the current crash track trolley. The study investigated not only the current set-up, parts and propulsion at the crash track but also the testing methods at other crash tracks and the possibility to implement them at ATC. Time was spent at the crash track, taking part in the daily work of the staff to have a better understanding of the process with the ambition to deliver a product that would function according with requirements.

3.2 Concept development, evaluation and improvement

The costs of a product during manufacture, in use and the future can be determined in the development stage. With careful, creative and systematic work methods it is possible to achieve quality at a low cost. Don Clausing, one of the early pioneers in quality and product development, introduced an iterative process with three different stages at product level which he called requirements, concepts and improvement. At the requirement stage the needs and expectations from the customer is gathered, evaluated and translated into product requirements. In the concept stage different concepts are generated that satisfy the customer’s needs. In the final stage the concept should be improved using systematic methodologies, design of experiments and robust design. The final stage is directed at products intended for mass production which is less topical for this thesis. (Bergman & Klefsjö 2014)

Concept selection is often performed in two stages when evaluating dozens of product concepts. Screening, which is a quick and approximate evaluation aimed at selecting a few viable alternatives and scoring, which is a more careful analysis with few concepts and the goal to choose a single concept with the most likelihood of success. The selection is preferably done in an evaluation matrix. (Ulrich & Eppinger 2012)

In this thesis different concepts were brought forward with regard to what was found of importance in the feasibility study. Since only four concepts were evaluated it was decided that scoring was the only evaluation needed to proceed with selection. Concepts were discussed with senior engineers at Autoliv and the choice for further development was based on mutual agreement with the staff.
3.3 Computer Aided Design

Catia V5 is software developed by Dassault Systèmes used throughout Autoliv and most of the automotive industry. To visualize the product, CAD-models were drawn up in Catia V5. This was done by acquiring drawings of the original trolley made in aluminum. Since the trolley had been redesigned into steel by external manufacturers no drawings of the current trolley could be found. Due to this issue all measurements required confirmation by measuring dimensions directly on the trolley. Another purpose of modeling the trolley was to make sure that there was enough space for the ideas brought forward in the feasibility study. Lastly, Catia V5 was used make 2D drawings. The drawings are attached as Appendix 2 in this report.

Other software used in this thesis was Microsoft Visio, used to schematically visualize the crash test process and Creo Parametric 3.0, used to design a cross-section of the crash track.

3.4 FEM-Analysis

The Finite Element Method is a general numerical method aimed at solving mechanical problems. The method can be applied to large-scale areas such as flow, acoustics, magnetic fields and dynamic problems. FEM-programs are often application specific and can be used to simulate possible combinations of load cases and parameter values. Calculations can be used in the pre-conceptual phase to find important weaknesses in the design. FEM is an extremely powerful tool when integrated into product development and can provide important guidance in both conceptual and detailed design. With a large material database it is possible to have a closer look at physical problems and calculating what seemed impossible 40 years ago. It takes three steps to do a FEM analysis:

1. Creation of the geometrical model
2. Choice of material, forces (thermal or dynamical) and application of boundary conditions
3. An analysis is run by the computer and equations are solved. How long the analysis takes is depending on the scale of the problems and the power of the computer

(Persson 1999)

The field of application for this thesis is structural mechanics and more specifically strength analysis. A FEM-analysis was made on the winning trolley concept by Kenneth Backman, senior simulation engineer at Autoliv. The purpose of the simulation was to analyze the strength of the trolley in two different load cases. By simulating the construction and affecting forces, the potential in thinning the trolley without compromising its integrity was examined. The results were used as guidelines in the designing process and for the final recommendation. A report containing the FEM-analysis is attached as appendix 1 in this thesis.
3.5 Energy calculations

Energy calculations are used in this thesis to evaluate the increased stress on the facility and brake tubes, whose task it is absorb all energy produced. To calculate kinetic energy, basic physics is used. The energy produced during the acceleration phase is directly related to the speed and mass of the trolley which can be calculated by equation 1: (Alphonce & Pilström 2010)

\[ E_k = \frac{mv^2}{2} \quad \text{Eq. 1} \]

Where \(E\) [J] is the kinetic energy produced, \(m\) [kg] is the mass and \(v\) [m/s] is the velocity. Current mass of trolley can be seen in table 2.

Table 2. Weight calculation table

<table>
<thead>
<tr>
<th>Part</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trolley plate</td>
<td>47 kg</td>
</tr>
<tr>
<td>Clamp</td>
<td>9.25 kg</td>
</tr>
<tr>
<td>Top attachment</td>
<td>2.523 kg</td>
</tr>
<tr>
<td>NHTSA Oblique yellow attachment</td>
<td>15.7 kg</td>
</tr>
<tr>
<td><strong>Calculated weight</strong></td>
<td>74.473 kg</td>
</tr>
<tr>
<td>Weight round-up (screws, support attachment)</td>
<td>5.527 kg</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>80 kg</td>
</tr>
</tbody>
</table>

The velocity required to perform the NHTSA Oblique is 90 km/h which is 25 m/s. The total weight of the trolley is 80 kg which inserted into equation 1 gives:

\[ E_k = \frac{80\, \text{kg} \times 25^2}{2} = 25000 \, \text{J} \]

The kinetic energy that is currently absorbed by the brake tubes when performing NHTSA oblique 90km/h is 25 kJ.
4 Results
This chapter contains the results of the thesis. Firstly, a feasibility study containing information about crash track trolleys in other locations is presented. The chapter contains a requirement specification, the different concepts and an evaluation of the concepts. Lastly the winning concept is developed further and the effects on components and the crash track are examined.

4.1 Trolley feasibility study
Crash testing is performed in many places around the world. Depending on the geographical location, the crash track needs to perform according with the rules of the local vehicle safety regulations. The testing method at ATC is unique since it was constructed to fit the facility and its customer’s needs. Other crash testing departments have their own method of testing which is dependent on their own needs. Some departments choose to have their crash track entirely manufactured by external providers while some have methods that have been developed by their own engineers.

In figure 15 the crash track trolley at ATC 2 is seen, which is one of the laboratories owned by Autoliv in the United States. The trolley differs from ATC Vårgårda regarding clamping method, function and centralization toward the track. This method has advantages since the trolley can be constructed specifically to fit inside the track. The width and length of the trolley does not affect the performance which is seen in the two different designs on the same track in figure 15.

![Figure 15. ATC 2 crash track trolley](image)

The trolley differs in both clamping and track fitting method. Where the trolley at ATC has a rolling mechanism towards the rail, ATC 2 uses a sliding one observable in figure 16. The clamp is also seen in to the left in figure 16.
Messring is one of the largest crash track manufacturers in the world. Autoliv is a major customer and has used the services of Messring when constructing new crash tracks or improving old facilities. Messring has developed a trolley which is specifically made for their “micro-track” system. The trolley is positioned inside the track with the wire running through it. The trolley is able to drive both ways, can perform oblique testing by setting it to a specific mode and is rather light in terms of weight. Since the trolley is positioned inside the track it does not take up space at the testing facility and can be crossed with cars and industrial trucks. (Messring 2016)
4.2 Requirement specification

The requirement specification has been compiled with the requirements and wishes of the staff working with the trolley on a daily basis. All information was gathered by interacting with technicians and obtaining information on site.

Table 3. Trolley requirement specification

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Request</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight below 160 kg (Two connected trolleys)</td>
<td>Easier maintenance</td>
</tr>
<tr>
<td>Operational</td>
<td>Manufacturing at Autoliv</td>
</tr>
<tr>
<td>Robust</td>
<td>No change on work method</td>
</tr>
<tr>
<td></td>
<td>Trolley plate redesign</td>
</tr>
</tbody>
</table>

Weight below 160 kg – The current solution to the trolley problem has been to double the clamp force by connecting two trolleys. This solution has worked except for troubles with the kinetic energy being too large. Due to this the design should not exceed the weight of two trolleys.

Operational – The new trolley needs to function at current conditions without implications on the track or wire.

Robust– The trolley must not be bend, tear or break when it is affected by the forces acted upon it during testing.

Easier maintenance – Technicians working with the trolley have requested easier removal from the track for maintenance.

Manufacturing at Autoliv – The trolley is requested to be made at the workshop at Autoliv.

No change on work method – The clamp mechanism is tightened with a tool specifically made for the current clamping method. If the clamp mechanism is changed - work method, tools and routine also needs adjustment.

Trolley plate redesign – After discussion with group manager Erik Bjelkemyr it was decided that the main development focus should be on the trolley plate.

4.3 Concept trolley plate

In this chapter the different concepts are presented and evaluated. The focus during the concept generation was on the trolley plate. This was done due to the previous double clamp method being successful. The goal was to bring forward a concept that fits two clamps but is lighter in terms of weight. One concept regarding development with the clamp mechanism was also brought forward and a total of four concepts are presented in this chapter. Three of the concepts were drawn in Catia V5 and one was discussed. Lastly the concepts were evaluated in a concept matrix.
4.3.1 Concept 1 – Unchanged trolley plate
Concept 1, seen in figure 18, is the current trolley in use. The purpose of designing the current trolley was to investigate the possibility to keep the plate. This design could not fit two clamps which would require redesigning of the clamp mechanism to increase clamp force. This concept would require extensive research and redesigning – which was not preferable.

![Figure 18. Concept 1](image)

4.3.2 Concept 2 – Double clamp, optimized weight
Concept 2, seen in figure 19, is an elongated version of the original trolley. The trolley has room for two clamps to achieve the same effect as the previous “double trolley solution”. By using the same design, only elongating the trolley, further investigation can be put into thinning the trolley which could decrease weight and energy during testing.

![Figure 19. Concept 2](image)
4.3.3 Concept 3 – Double clamp, three wheels

Concept 3, seen in figure 20, is an elongated version of the original trolley with three wheels. Removing one wheel could make it easier for technicians to maintain the trolley since the wheels take up space inside the crash track. However, designing the trolley asymmetrical could cause extra stress on the trolley which may result in plastic deformation.

Figure 20. Concept 3

4.3.4 Concept 4 – redesigning the trolley

The last concept discussed but not drawn up in Catia V5 was the idea to remake the trolley entirely. This remake would be based on information found in the trolley feasibility study with the goal to make a modern trolley with minimal weight. It is considered a very extensive construction since all aspects of the trolley need to be investigated, constructed and tested. Since ATC uses a rolling mechanism, the trolley design at ATC 2 cannot be used.

4.3.5 Concept evaluation

The concept evaluation matrix, seen in table 4, was performed without consulting the grading system with staff. The criteria were based on the requirement specification. The different concepts were also discussed with technicians resulting in a final row -“Approved for further development”. The criteria are directly related to the function of the trolley and should be perceived as following:

**Function** – The concept will cause an improvement to the trolley and function correctly while performing the “NHTSA Oblique 90 km/h”
**Solidity** – The concept will not compromise the integrity of the trolley – no plastic deformation.
**Weight** – The concept will not exceed the weight max in the requirement specification.
**Manageable** – The concept will not cause the trolley to be unmanageable by staff.
The criteria were graded in a 5-grade system which should be perceived as following:

- 5 – The concept will satisfy the criteria
- 4 – The concept will most likely satisfy the criteria
- 3 – It is unsure if the concept will satisfy the criteria
- 2 – The concept will most likely not satisfy the criteria
- 1 – The concept will not satisfy the criteria

Table 4. Concept evaluation matrix

<table>
<thead>
<tr>
<th>Criteria</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Solidity</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Weight</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Applicability</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>15</td>
<td>18</td>
<td>14</td>
<td>12</td>
</tr>
</tbody>
</table>

Approved for further development: Yes Yes No No

The concept that received most points was concept 2 which also was the choice for further development. The work to develop concept 1 was considered too extensive although it was approved by staff.

### 4.4 Further development of concept

In this chapter the concept that received most points in the matrix is further developed. The content of the chapter is a CAD model of the new plate and the weight optimization. This chapter also examines the effect that the changes on the trolley plate will have on the rest of the components and energy calculations.

#### 4.4.1 Detailed model and weight optimization

The final plate design can be seen in figure 21. The reconstruction has allowed enough space for two clamps to fit, which gives the same results as the previous double trolley solution. The designing is identical to the previous trolley, which allows the tested vehicle to be positioned in the middle of the track, keeping the previous test routines. By keeping the design, the current clamps can be reused which causes minimal need for reconstructing new components. The goal during the redesigning was to keep the trolley as small as possible but still fitting two clamps which resulted in a length increase by only 205 mm.
The weight calculation of the trolley plate and different parts can be seen in table 5.

Table 5. Weight calculation table, new design.

<table>
<thead>
<tr>
<th>Part</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trolley plate</td>
<td>47 kg</td>
</tr>
<tr>
<td>Clamp x 2</td>
<td>18.5 kg</td>
</tr>
<tr>
<td>Top attachment</td>
<td>2.523 kg</td>
</tr>
<tr>
<td>NHTSA Oblique yellow attachment</td>
<td>15.7 kg</td>
</tr>
<tr>
<td><strong>Calculated weight</strong></td>
<td>83.723 kg</td>
</tr>
<tr>
<td>Weight round-up (screws, support attachment etc.)</td>
<td>6.277 kg</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>90 kg</td>
</tr>
</tbody>
</table>

Due to elongation of the trolley, the weight was increased. This was undesirable and an analysis of thinning the trolley was performed which is attached as Appendix 1 in this report. An extract from Appendix 1 containing a table with potentials for weight reduction can be seen in figure 22. The trolley plate as well as components and attachments with respective weights in different thicknesses can be observed in the table. The results of the analysis showed that it was possible to thin the trolley by 10mm. This thickness would save 13kg of mass which gives the new plate the same weight as the current single clamp plate. The total weight increase of the trolley is due to the second clamp being placed on the trolley and the extra screws needed to fit the clamp.
4.4.2 Redesigning issued on trolley components

Even though the original design is kept with the adjustments being made on length and thickness it will still have significant effect on components. Elongating and thinning the trolley results in issues for some of the components not fitting in the trolley plate. The detachable part of the track also needs refitting. The changes needed on component for the trolley to function as intended can be seen in table 5.

Table 5. Component issues

<table>
<thead>
<tr>
<th>Component</th>
<th>Issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trolley plate</td>
<td>Depths of holes need redesigning to fit the new trolley plate.</td>
</tr>
<tr>
<td>Adapter</td>
<td>The thickness needs to increase by 10mm to fit the new trolley plate.</td>
</tr>
<tr>
<td>Clamp connection pin</td>
<td>The clamp connection pin needs to be extended to fit both clamps. Since the pin needs to pass to clamps, the pin is made conic to easier pass the holes.</td>
</tr>
<tr>
<td>Detachable track</td>
<td>The new design has increased the length of the trolley by 205 mm. This requires the detachable part of the track to be increased to 720 mm.</td>
</tr>
<tr>
<td>Wire support attachments</td>
<td>The wire support attachments need to be placed on the outside of both clamps.</td>
</tr>
</tbody>
</table>
The new design of the adapter can be seen in figure 23.

Figure 23. New connection adapter

The new design of the clamp connection pin can be seen in figure 24.

Figure 24. New clamp connection pin
4.4.3 Energy calculations
The new trolley weight is 90 kg which is inserted into equation 1 to calculate the new kinetic energy.

\[ E_k = \frac{90 \times 25^2}{2} = 28125 \text{ J} \]

Which gives a total energy increase by 12.5 %

5 Conclusion
The assembly of the new trolley can be seen in figure 24. The purpose of this thesis was to design a trolley that could perform the NHTSA Oblique 90 km/h without slip. The previous solution to the issue was to double the clamp effect by connecting two existing trolleys. The intention of this design was to create the same clamp effect by fitting two clamps on one trolley plate. To achieve this effect the trolley plate needed to be elongated. This resulted in a weight increase which was undesirable. To keep the same weight, the plate was thinned by 10mm which resulted in an unchanged plate weight. However, the total weight was slightly increased by 10 kg due to a second clamp being attached. This weight increase was unavoidable but will have minimal effect since the double trolley solution had a weight of 160 kg and still managed to perform NHTSA Oblique 90 km/h.

![Figure 25. Double-clamp elongated trolley](image)

Unfortunately the early requirement to avoid implications on the crash track was unsuccessful. The double clamp system requires the trolley to be elongated and if so the detachable track needs to be adjusted to fit a larger trolley plate. The changes are minor, since it only requires a cutting of the crash track which can be done by technicians at ATC.
6 Discussion

The result of the report was not only a final design of the trolley but also the needed adjustments to be made at the crash track for the trolley to function as intended. In Appendix 2 the drawings of the trolley design is attached. Detailed drawings and 3D models are available at Autoliv in Vårgårda.

The major changes on the trolley were the slimming and elongation of the trolley plate. It was unsure if this change was safe and the physical integrity was analyzed with a FEM-analysis which gave a positive result. The results are however not guaranteed since the slimming of the trolley could cause more bending that may damage the structure. This is somewhat alarming and should be investigated further.

Early in the work it was chosen to proceed with changing the trolley plate. A question constantly raised during the work was if this was the right path to go. The investigation and feasibility study focused much on the current crash track and other crash tracks. Since the source of the issue was the clamping method and lack of clamp force these parts could be analyzed further. If clamping force can be increased there is no need to change the trolley design. Perhaps there are other areas where similar clamping methods are used that could be looked into. For example; ski lifts have different methods to clamp wagons to steel wire which perhaps could be of assistance at the crash track. It should be remembered though that the largest part of the trolley is the trolley plate, weighing approximately 47kg. Thinning the trolley by 10mm gives the plate a 25% weight reduction which is an essential aspect for the NHTSA Oblique 90km/h to work since the energy is reduced. This was the primary reason for the choice to change the trolley plate.

The new trolley does not make it easier for the staff to maintain the trolley. Although the pin was made conic to create an easier removal, the staff still needs to remove it in an awkward position. This is an issue that should be discussed further with the technicians working on the track.

The major reason for leaving the design unchanged was due to recommendations by technicians at the track. The question was raised early in the thesis to save weight by reducing the broad of the trolley, creating a new design. This was dismissed because of the change in centralization of the trolley which could affect all current testing. It was also raised to remove the wheels of the trolley but that was also dismissed due to uncertainty of function.

Lastly, this thesis was initially intended to be a two-part work. Beyond the trolley design, it was intended to make a feasibility study on changes to be made on the crash track for further development. Together with the trolley design it was planned to be one separate report. During the project it was however realized that the work was for to extensive and it was decided to only make a report on the trolley design. The results of the total work at Autoliv was this report, CAD models, drawings as well as an abstract given to the staff at ATC containing a 30-page long summary about the crash track and the possibilities for improvement. The summary took a lot of work which is one of the reasons for the timeframe being shorter for the trolley construction.
7 Further recommendations

To make sure that the trolley functions as intended a prototype plate should be made to test the current trolley system. This trolley plate should be constructed with a thickness of 30mm. By not changing the plate length and keeping the original design, it will fit in the track which gives an opportunity to test the thinner plate without making adjustments. Giving the proper time to test the change in trolley plate, the effects of the thinning can be analyzed.

If an elongated trolley is undesirable, the clamp system should be investigated further.
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Appendix 1 – FEM-Analysis
Scope

1. Analyse the strength of the trolley in two different load cases
   a) Constant acceleration of 4.56 m/s²
   b) Retardation from 90 km/h using crush tubes

2. Reduce the weight without jeopardising the integrity of the trolley i.e. no plastic deformation is allowed
Description – Acceleration model

A lumped mass of 2600 kg
NOTE! Only the weight of the cart is implemented. Friction between the wheels and the ground is not considered.

Rail modelled as rigid

Clamps rigidly attached to the wire

Prescribed acceleration = 4.55 m/s²

Wheels connected via analytical joints

Adaptors connected via rigid bodies
Description – Retardation model

- Initial velocity = 25 m/s
- Rail modelled as rigid
- Crush tubes rigidly attached
- Wheels connected via analytical joints
- Adaptors connected via rigid bodies
Material

Calculated Stress versus Strain for material: Trolley

Only information regarding the yield strength of the material was available and thus a very simplified material model was created. The model would however still be able to detect plastic deformation which allows for an easy analysis.
Animation – Acceleration model

Time = 0

Animates in slide show mode
Animation – Retardation model

Time = 0

Animates in slide show mode
## Weight reduction

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Mass 1</th>
<th>Mass 2</th>
<th>Mass 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 mm</td>
<td>85 kg</td>
<td>71 kg</td>
<td>53 kg</td>
</tr>
<tr>
<td>30 mm</td>
<td>72 kg</td>
<td>58 kg</td>
<td>40 kg</td>
</tr>
<tr>
<td>20 mm</td>
<td>59 kg</td>
<td>45 kg</td>
<td>26 kg</td>
</tr>
</tbody>
</table>

Bolt, clamp levers, tube contact plates etc. are not included in the mass calculation.
Retardation – Plastic strain

At 20 mm plastic strain starts to show at the adaptor attachment. However, the values are small and the bolt are not modelled in detail.
Retardation – Plastic strain

As the trolley impacts the tubes a (very) small amount of plastic strain can be seen on the rear, right hand wheel. This can be result of the somewhat uneven weight distribution due to the clamps being attached to the opposite side. No risk of failure but can add to the wear of the wheel. (However, this is very dependent on gap between wheels and rail, tolerances, radii etc. which is not studied in detail in this model)
Retardation model modified

Connection removed in order to study the strength of the trolley plate without being reinforced by the cart attachment adaptor.
Retardation – Plastic strain

At 20 mm plastic strain starts to show at the adaptor attachment. However, the values are small and the bolt are not modelled in detail.
Conclusions / Discussion

Conclusions

1. Reducing the thickness of the trolley plate to 30 mm seems to be safe

2. At 20 mm thickness plastic strain starts to occur and is therefore not recommended (at least not without changing the material grade).

One should also remember that even though plastic strain do not occur the bending of the plate become larger with a thinner plate and the misalignment could put more strain on wheels, rail etc.

NOTE! Unquantified parameters like friction, oscillations etc. can add to the load on the trolley

Discussion

Especially considering the acceleration phase - are there other load cases where the trolley plate is not reinforced by the cart attachment (which creates a rather stiff box)?
Appendix 2 - Drawings